

Grain-Size and Geochemical Characteristics of Surface Sediments from Giant Sand Ripple Stripes in the Qaidam Basin (Postprint)

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Abstract

Megaripple stripes (MRS) are a type of longitudinal aeolian landform where megaripples are distributed in stripes parallel to the flow direction, including Megaripple corridors (MRC) with relatively larger megaripple sizes and Smaller bedform corridors (SBC) with relatively smaller sizes. A total of 112 surface sediment samples were collected from MRS in the Qaidam Basin and analyzed for their physical properties (grain size characteristics) and chemical properties (major and trace elements). The results indicate: (1) In the MRS surface sediments of the Qaidam Basin, the dominant grain size fractions of MRC are gravel (44.24%~50.19%) and very fine sand (15.91%~20.42%), exhibiting a bimodal grain size distribution; the dominant grain size fractions of SBC are very coarse sand (26.00%~35.90%) and fine sand (14.80%~20.47%), exhibiting a trimodal grain size distribution. (2) The MRS are very poorly sorted, with predominantly positive skewness and broad to very broad kurtosis. (3) The elemental contents show little difference between MRC and SBC. The major elements are dominated by SiO₂ and Al₂O₃, with contents of approximately 63% and 10%, respectively; the trace elements are dominated by Cr, Co, Mo, and Ba. Except for Cr and Mo, all other elements are in a state of leaching and loss. (4) The MRS in the Qaidam Basin exhibit low-degree chemical weathering under cold and arid conditions, representing an early stage of continental weathering with relatively stable chemical weathering erosion.

Full Text

Preamble

Characteristics of Grain Size and Geochemical Element Composition of Surface Sediments of Megaripple Stripes in the Qaidam Basin

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Megaripple stripes represent a poorly understood aeolian landform, and comprehensive research on their physical and chemical properties remains scarce. Inverted river channels, a fluvial-like positive topography exhibiting dendritic and conical forms [22,25], are also weakly studied. The study area experiences a typical plateau continental climate. Given this knowledge gap, this study collected extensive surface sediment samples from the Qaidam Basin to analyze their physical and chemical properties, examining material composition and sorting characteristics. The results provide a valuable reference for subsequent investigations into the formation, evolution, and aeolian erosion-deposition processes of these landforms.

1.1 Study Area Overview

The Qaidam Basin is one of China's three major inland basins, covering an area of approximately 24×10^4 km². The basin extends to the Altun Mountains in the northwest, the Kunlun Mountains in the southwest, and the Qilian Mountains in the northeast, forming a roughly triangular shape [2]. Megaripple stripes are widely distributed across the central and southern Qaidam Basin. This study focuses on this region (36°20'04" N, 94°55'45" E; elevation 2824 m), which falls under the jurisdiction of Golmud City, Haixi Mongolian and Tibetan Autonomous Prefecture, Qinghai Province. The area features a typical plateau continental climate, with summer mean temperatures around 17.1°C and winter means around -7.8°C. Annual precipitation is low and concentrated in the warm season. While these bedforms appear distinct in imagery, they are difficult to identify in the field. The regional drift potential is 37.9 VU, indicating a low wind-energy environment, with a resultant drift direction of $285^\circ \pm 10^\circ$ and prevailing westerly and northwesterly winds [16,19-23].

1.2 Sample Collection

Most megaripples in the study area have wavelengths below 2 m, making them difficult to resolve in the field. We selected locations with larger dimensions for sampling (Figure 1). Megaripple stripes with wavelengths around 5 m can be roughly distinguished as banded features (Figure 1). In July, we collected surface sediment samples in situ, with sampling positions including windward slopes, crests, and leeward slopes. All samples were collected within a 5 cm × 5 cm area at a depth of 0–2 cm. The sampling locations included various developmental stages of megaripple corridors (MRCs), which mostly develop on the leeward side of inverted river channels. MRS denotes megaripple stripes; MRC denotes megaripple corridors; SBC denotes smaller bedform corridors; and the upwind area of megaripple stripes represents conventional megaripples.

Fig. 1 [Figure 1: see original paper] Sampling point distribution

1.3 Analytical Methods

Surface sediment physicochemical properties include physical and chemical characteristics. Physical properties primarily involve grain-size-related features. Samples with particle sizes >2 mm were sieved; samples with sizes <2 mm were measured using a Mastersizer3000 laser particle size analyzer (measurement range 0.01–3500 μ m) manufactured by Malvern Panalytical. After data normalization, grain size parameters including mean grain size, sorting coefficient (σ), skewness, and kurtosis (K) were calculated using GRADISTAT software, with grain size fractions classified according to the Udden-Wentworth standard [28,29]. Chemical properties mainly include chemical elements and chemical weathering characteristics. Samples were ground into powder, pressed into tablets, and elemental composition was determined using a BRUKER X-ray fluorescence spectrometer.

2.1.1 Grain Size Distribution

Megaripple stripes are essentially composed of individual megaripples, with grain size composition similar to megaripple characteristics. The MRC grain size distribution is bimodal, while SBC shows a trimodal distribution (Figure 2). The dominant grain sizes in MRCs are gravel and very fine sand. Gravel content ranges from 44.24% to 50.19% (mean 47.47%), while very fine sand content ranges from 15.91% to 20.42% (mean 17.24%). From generation to disappearance, very coarse sand content shows an increasing trend. After gravel and very fine sand, fine sand has the highest proportion, while coarse and medium sands have the lowest contents, ranging from 2.30% to 5.33%. The dominant grain sizes in SBCs are very coarse sand and fine sand. Very coarse sand content ranges from 26.00% to 35.90% (mean 29.98%), while fine sand content ranges from 14.80% to 20.47% (mean 18.44%). Medium sand content is lowest, ranging from 0.17% to 2.87%. The grain size composition shows clear bipolar differentiation (Table 1). Along the stripe direction, very coarse sand content fluctuates and increases, gradually becoming dominant. It is evident that the grain size of SBCs is smaller than that of MRCs.

Probability cumulative curves reflect the relationship between sediment grain size distribution and transport mode, which can be used to infer formation and development environments [31]. Most probability cumulative curves of aeolian sediments are located to the left of the 50% line, with most positions having slopes greater than those of MRCs, indicating more frequent and intense aeolian activity [5]. Although both have some significantly different individuals, the overall trend of probability cumulative frequency variation remains consistent.

Fig. 2 [Figure 2: see original paper] Grain size frequency and cumulative frequency curves of surface sediments at MRS

Tab. 1 Grain size distribution of surface sediments at MRS

Note: MRS = megaripple stripes; MRC = megaripple corridors; SBC = smaller

bedform corridors. The same below.

2.1.2 Grain Size Parameters

Overall, grain size parameter variations show consistency. The mean grain size ranges from -0.09 to 0.26 for MRCs and from 1.71 to 2.75 for SBCs, with means of 0.50 and 2.01, respectively, and standard deviations around 1.66. The mean grain size at all locations fluctuates violently with large amplitude. The sorting coefficient ranges from 2.01 to 2.37 for MRCs (mean 2.26) and from 2.04 to 2.27 for SBCs (mean 2.16), indicating very poor sorting. Skewness ranges from 0.55 to 0.84 for MRCs (mean 0.67) and from -0.48 to 0.85 for SBCs (mean 0.43), with both positive and negative skewness but predominantly positive, indicating that sediments contain a “fine tail” where finer particles enter and are trapped within coarser particle gaps [31]. Although grain size parameters differ somewhat between locations, the overall trend remains consistent.

Kurtosis values range from 1.70 to 4.85 for MRCs (mean 2.99) and from 0.54 to 1.12 for SBCs (mean 0.82), indicating very wide to extremely wide peaks. The kurtosis of MRCs is slightly better than that of SBCs. From windward slope to leeward slope of megaripples, the mean grain size first decreases, then gradually increases past the crest. Coarse particles accumulate at the crest, so the crest position has the smallest mean grain size value, indicating the coarsest particles. The sorting coefficient is 2.04–2.27 (mean 2.16), indicating very poor sorting. Kurtosis is 1.87–2.26 (mean 2.01), indicating wide to very wide peaks. Skewness is 0.43–0.50 (mean 0.47), showing positive skewness. Along the ridge line direction, the mean grain size ranges from -0.25 to 0.50 (mean 0.33). The sorting coefficient is 2.04–2.27 (mean 2.16), indicating very poor sorting. Skewness ranges from 0.43 to 0.50 (mean 0.47), all positive. Kurtosis varies significantly, being very wide at most locations but narrow at MRC3-9 wing angles.

Fig. 3 [Figure 3: see original paper] Grain size parameters of surface sediments at MRS

2.2.1 Geochemical Element Characteristics

Sediment chemical element composition can reflect provenance, depositional environment, and weathering degree to some extent [12,18]. In MRS surface sediments, SiO₂ content dominates absolutely, ranging from 61.22% to 64.09% in MRCs and 62.43% to 65.83% in SBCs, with a mean of 62.05%. Al₂O₃ content is second, ranging from 9.09% to 10.39% in MRCs and 9.59% to 10.03% in SBCs, with a mean of 9.82%. Fe₂O₃ content ranges from 2.99% to 3.76% in MRCs and 3.44% to 3.86% in SBCs, with a mean of 3.40%. Other major elements do not exceed 4.85% (Table 2). All major element variation coefficients are less than 0.15, indicating no significant content variation across different locations and suggesting similar sediment provenance.

Compared with the Badain Jaran, Tengger, Kumtagh, and Taklamakan deserts,

each major element shows some content differences (Table 2). The Fe_2O_3 content is closest to that of the Taklamakan Desert (3.40%) but lower than other deserts. Al_2O_3 content is higher than these deserts, while SiO_2 content is relatively lower [13,22]. Normalized to the upper continental crust (UCC), all major elements in Qaidam Basin MRS surface sediments are depleted (UCC-normalized values <1), indicating they are in a leaching and migration state (Figure 4). Trace elements in MRS surface sediments are dominated by Cr, Co, Mo, and Ba, with average contents $>115 \text{ g} \cdot \text{g}^{-1}$. Similar to major elements, trace element contents show little overall variation, with variation coefficients <0.15 . Compared with UCC, Cr and Mo have normalized values >1 , showing enrichment, while other trace elements show depletion. For Co and Ba, the opposite is true: Co shows depletion while Ba shows enrichment. All other trace elements and major elements are depleted.

Fig. 4 [Figure 4: see original paper] UCC-normalized pattern of geochemical elements for surface sediments at MRS

Tab. 2 Content of major elements in surface sediments at MRS

Note: – indicates no data.

2.2.2 Chemical Weathering Characteristics

The Rb/Sr ratio is an indicator of sediment chemical weathering degree, where larger ratios indicate higher weathering intensity [36]. MRS surface sediments have Rb/Sr ratios of 0.21–0.26, lower than the Badain Jaran (0.37–0.42), Tengger (0.40–0.56), and Mu Us (0.15–0.56) deserts, indicating weaker chemical weathering in the Qaidam Basin [16,19–23,26]. The chemical index of alteration (CIA) can also reflect weathering degree and infer depositional climate conditions [21,36]. CIA values of 49.15–53.95 indicate a cold, dry depositional environment with low chemical weathering, consistent with previous results. The weathering degree is higher than that of Chinese loess but lower than other deserts.

To reflect compositional and mineral changes during chemical weathering and weathering trends, A-CN-K and A-CN-K-FM ternary diagrams are commonly used [21,36]. Projecting the main chemical composition of Qaidam Basin MRS surface sediments onto these diagrams and comparing with Chinese loess and terrigenous shale reveals that MRS plots near the A-CN line endpoint, indicating an early stage of continental weathering characterized by relatively stable conditions (Figure 5). This stage involves plagioclase weathering [35]. Alkali metal element contents are similar to UCC and spatially stable because the cold, dry climate limits alkali metal mobility, making them less susceptible to leaching [12].

Fig. 5 [Figure 5: see original paper] A-CN-K and A-CN-K-FM ternary plots of surface sediments at MRS

3 Discussion

Simulation results indicate that coarse particle content is critical for Gough formation, and MRS formation conditions share similarities with megaripples [39]. It is widely accepted that megaripple formation requires bimodal or multimodal grain size distributions [5,34,38], which is confirmed by the bimodal distribution of MRCs and trimodal distribution of SBCs. Coarse particles concentrate at certain locations and expand downwind to form MRCs, while locations with insufficient coarse particles gradually develop into SBCs. The coarsest sand grains in the Qaidam Basin can reach 5.04 mm, larger than most megaripples reported in current studies [34,40-42] and larger than known megaripples in other regions [5]. Additionally, coarse particle accumulation at crests forms a protective layer that inhibits wind erosion to some extent. The MRS has higher coarse particle content than typical megaripples, giving it stronger wind erosion resistance and resulting in weaker wind sorting [38]. Both MRCs and SBCs show very poor sorting.

The unique morphology of MRS indicates a more complex formation process than typical megaripples. Based on the surrounding environment, we hypothesize that megaripples first form on the leeward side of inverted river channels and continuously develop. Locations along the ridge with relatively low coarse particle content are “broken” by wind erosion, gradually forming MRS through prolonged wind action. Field observations reveal that trough positions are lower than crest positions, indicating trough erosion. During formation, particle transport perpendicular to wind direction also occurs, consistent with previous conclusions [43].

The weathering degree in the study area is weaker than in other Chinese deserts [16,19-23]. Previous studies found certain correlations between sediment grain size and chemical elements. In the Yangtze River Basin, Rb/Sr ratios increase with decreasing grain size, whereas in gobi regions, Rb/Sr decreases with decreasing grain size [12,18]. In this study, the correlation between grain size variation and Rb/Sr ratio trends in Qaidam Basin MRS is not significant. CIA content consistently decreases along the wind direction, also showing no significant relationship with grain size variation. This is because: (1) Qaidam Basin MRS surface sediments have dominant grain sizes of gravel (44.24%–50.19%) and very fine sand (15.91%–20.42%), showing a bimodal distribution; SBCs have dominant grain sizes of very coarse sand (26.00%–35.90%) and fine sand (14.80%–20.47%), showing a trimodal distribution. (2) Sorting is very poor for both, with kurtosis ranging from wide to very wide, and both positive and negative skewness exist but positive skewness dominates. (3) Although both have some significantly different individuals, the overall trend of probability cumulative frequency variation remains consistent.

MRS surface sediments are dominated by major elements SiO_2 and Al_2O_3 , with SiO_2 content reaching ~63% and Al_2O_3 content ~10%. Other major elements do not exceed 4.85%. All major element variation coefficients are <0.15 , indicating

no significant content variation across locations. Trace elements are dominated by Cr, Co, Mo, and Ba, with overall stable content (variation coefficients <0.15). Compared with UCC, Cr and Mo show enriched states (normalized values >1), while other trace elements and all major elements are depleted. The low chemical stability of ferromagnesian minerals makes them susceptible to weathering, fragmentation, and enrichment in finer particles under wind transport and erosion. Since MRS surfaces are relatively coarse, no increasing trend in element content is observed. Current research and data are insufficient to fully reveal MRS formation mechanisms, and many questions remain unresolved, requiring further investigation.

4 Conclusions

This study analyzed the grain size and chemical element composition characteristics of MRS surface sediments in the central and southern Qaidam Basin through field sampling, providing a reference for related research. The main conclusions are:

- (1) In MRS surface sediments, the dominant grain sizes are gravel (44.24%–50.19%) and very fine sand (15.91%–20.42%), showing a bimodal distribution. SBCs have dominant grain sizes of very coarse sand (26.00%–35.90%) and fine sand (14.80%–20.47%), showing a trimodal distribution.
- (2) Sorting is very poor for both MRCs and SBCs, with kurtosis ranging from wide to very wide. Both positive and negative skewness exist, but positive skewness dominates. Although some significantly different individuals exist, the overall trend of probability cumulative frequency variation remains consistent.
- (3) MRS surface sediments are dominated by major elements SiO_2 and Al_2O_3 , with SiO_2 content ranging from 61.22% to 65.83% and Al_2O_3 content not exceeding 10.39%. All major element variation coefficients are <0.15 , indicating no significant content variation across locations. Trace elements are dominated by Cr, Co, Mo, and Ba, with stable overall content (variation coefficients <0.15). Compared with UCC, Cr and Mo show enrichment, while other trace elements and all major elements are depleted.
- (4) From a weathering perspective, Qaidam Basin MRS experienced low chemical weathering in a cold, dry environment, weaker than other deserts but stronger than Chinese loess. MRS is in the early stage of continental weathering, with composition closely resembling UCC and stable, concentrated distribution, indicating relatively uniform chemical weathering across locations.

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